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Channel Utilization of a Scout/Follower Broadcast System

I Introduction and Summary

In this note we shall evaluate the channel utilization of a direct terminal-to-terminal broadcast system which we call the scout/follower broadcast system. We assume that inter-area traffic must be routed to a station; however, the scout/follower system might be a possible candidate for handling intra-area (i.e., local) traffic. The approach used herein is a steady-state analysis similar to that used by N. Abramson in Ref. 1 and by the author in Ref. 2.*

The scout/follower broadcast system consists of terminals and repeaters. We assume that the location of the destination terminal is not known to the source terminal. Consequently, the source terminal floods the network with scout packets in order to find the destination terminal. Subsequent follower packets from the source terminal to the destination terminal are then routed along the sequential chain of repeaters traveled by the scout packet which successfully found the destination terminal.

Although flooding the network is inefficient (see Ref. 2), the scout/follower system may have acceptable channel utilization if the total number of packets in a given communication from the source terminal to the destination terminal are large (i.e., the ratio of the number of scout packets to follower packets is small). This is a likely possibility for terminal-to-terminal voice communication.

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*Ref. 1: N. Abramson, "THE ALOHA SYSTEM--Another Alternative for Computer Communication," AFIPS Conference Proceedings, Vol. 37, pp. 281-285, November 1970

Ref. 2: P. J. Wong, "Channel Utilization of a Slotted Ripple System," Packet Radio Temporary Note 23, February 5, 1973.

In this note, we shall make a number of simplifying assumptions and approximations (which are not strictly true) in order to make the analysis more tractable. Our intent is to obtain "rule-of-thumb" answers concerning the behavior of the scout/follower system. For example, we have found for a 37 repeater network and a 600 packet terminal-to-terminal voice communication that:

(i) The maximum useful traffic which can be offered by terminals in a single repeater area (which we call channel utilization) is .011, and for the combined 37 repeater areas it is .407,

(ii) The price paid for flooding the network to find the destination terminal is a 23% drop in channel utilization, and

(iii) The repeater, in the special case where the location of the destination terminal is known, spends 15% of its active time handling packets for which one of its own terminals is either the sender or receiver, 23% of its active time handling packets for which one of its own terminals is neither the sender nor receiver, and 62% of its active time being interfered by the neighboring repeaters..

II A Description of a Scout/Follower System

There are many different ways to implement a scout/follower system; it is not clear which way is best. However, in order to provide a framework for analysis, we shall describe one possible implementation of a scout/follower system. It is to be emphasized that the analysis results presented in this note are not sensitive to the particular method of implementing a scout/follower system, and that the system described below is mainly included for purposes of illustration.

We assume that terminals and repeaters can only broadcast in time slots. Also, we assume hop-by-hop acknowledgement. More specifically, if a repeater or terminal receives a packet for which it has been designated as the receiver (repeater or terminal), then it sends to the sender (repeater or terminal) an acknowledgement packet. If the sender does not receive an acknowledgement packet, then it will rebroadcast a copy of the original packet until it receives an acknowledgement packet. For ease of analysis, we assume that the acknowledgement packet is infinitesimally small, thus, implying non-interference between acknowledgement packets and other packets. Also, we assume that acknowledgement packets are received with probability equal to one. Although this acknowledgement process is unrealistic, it may be a good approximation to schemes where the acknowledgement packet is transmitted on a separate frequency with high probability of success (e.g., ALOHA) or where acknowledgement packets are much smaller than regular packets and are transmitted in designated time slots different from regular time slots with a high probability of success.*

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* There are many important considerations in designing an acknowledgement process (e.g., separate frequency, separate slots, positive acknowledgement, passive acknowledgement). In order to make progress in this note, we are essentially avoiding the details of the acknowledgement process. We feel that certain questions concerning the regular broadcast process can be studied apart from the acknowledgement process and vice versa. We expect the problems concerning the acknowledgement process to be equally as difficult as the problems for the regular broadcast process.

In order to keep multiple copies of a packet from saturating the system, we assume that a repeater will not relay another copy of a packet, if it has already successfully relayed a copy of the packet to the designated receivers. This single relay constraint is analogous to the single repetition constraint for the ripple system (see Ref. 2).

To find the destination terminal, we assume that the source terminal floods the network with scout packets. More specifically, when a repeater receives a scout packet for the first time, it relays the scout packet to all neighboring repeaters. Because we've assumed hop-by-hop acknowledgement, the repeater may have to rebroadcast the scout packet many times until it receives an acknowledgement from all the neighboring repeaters. Because of the single relay constraint, a repeater which has successfully relayed a scout packet to all neighboring repeaters, will not relay a scout packet a second time if it receives another copy of the scout packet.

We assume that a scout packet has a memory on which the repeaters can write. Each time a repeater relays a scout packet, the repeater places its ID in sequence in the memory. When a scout packet reaches the destination terminal, it will have stored in its memory a sequential list of repeaters it went through.

In order to establish the direct route from the source terminal to the destination terminal found by the scout packet, the destination terminal sends to the source terminal, over the reverse route traveled by the scout packet, a tracker packet. In particular, the tracker packet contains (1) the source and destination terminal's ID, (2) the sequential list of repeaters traveled by the scout packet, and (3) a handover number. When a tracker packet is received by a repeater, the repeater first checks the handover number to decide how many times it

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has been relayed. From the handover number and the sequential list of repeaters, it can decide whether it is the next repeater in line to relay the packet. If the repeater is the next in line to relay the packet, then it relays the packet and increases the handover number by one. Because we've assumed hop-by-hop acknowledgement, the repeater will rebroadcast the tracker packet until it receives an acknowledgement from the next receiver in line. Additionally, when the repeater relays the tracker packet it stores in its own memory (1) the source and destination terminal of the tracker packet, and (2) the repeaters immediately in front and in back of itself on the sequential list of repeaters contained in the tracker packet.

Subsequent follower packets can travel the route found by the scout packet and established by the tracker packet as follows. The header of a follower packet contains the source and destination terminal's ID, and the ID of the repeater next in line to relay the packet. When a repeater receives a follower packet it checks the header to see if it should next relay the packet. If its ID is specified as next to relay the packet, then the repeater uses the source and destination terminal information in the header, to determine from its memory which repeater is next in line after itself to relay the packet. The repeater then places the ID of the next repeater in the header of the follower packet and relays the packet. Because we've assumed hop-by-hop acknowledgement, the repeater rebroadcasts the follower packet until it receives an acknowledgement from the next receiver in line.

III Preliminary Definitions and Assumptions

In our model we shall keep track of several types of packets. First, we distinguish between packets broadcast by terminals and repeaters. Second, we differentiate between the first-time broadcast of a packet, and the rebroadcast of copies of the original packet. Third, we discriminate between a "scout" packet, a "tracker" packet, and a "follower" packet. Finally, for packets broadcast by a repeater, we distinguish between "own" packets generated by terminals in the repeater's area of coverage, and "other" packets generated by terminals in another repeater's area of coverage. When we do not wish to differentiate between packet types we shall simply use the term packet.

Referring to Fig. 1, the following are some of the preliminary definitions and assumptions used in the analysis. (Other definitions and assumptions will be given during the analysis.)

- Terminals in a repeater's area broadcast first-time scout packets at a total rate r_{s1}.
- Terminals in a repeater's area rebroadcast scout packets at a total rate r_{s2}.
- Terminals in a repeater's area broadcast first-time tracker packets at a total rate r_{t1}.
- Terminals in a repeater's area rebroadcast tracker packets at a total rate r_{t2}.
- Terminals in a repeater's area broadcast first-time follower packets at a total rate r_{f1}.
- Terminals in a repeater's area rebroadcast follower packets at a total rate r_{f2}.
- Terminals in a repeater's area broadcast at a total rate $(r_{s1} + r_{s2} + r_{t1} + r_{t2} + r_{f1} + r_{f2})$.

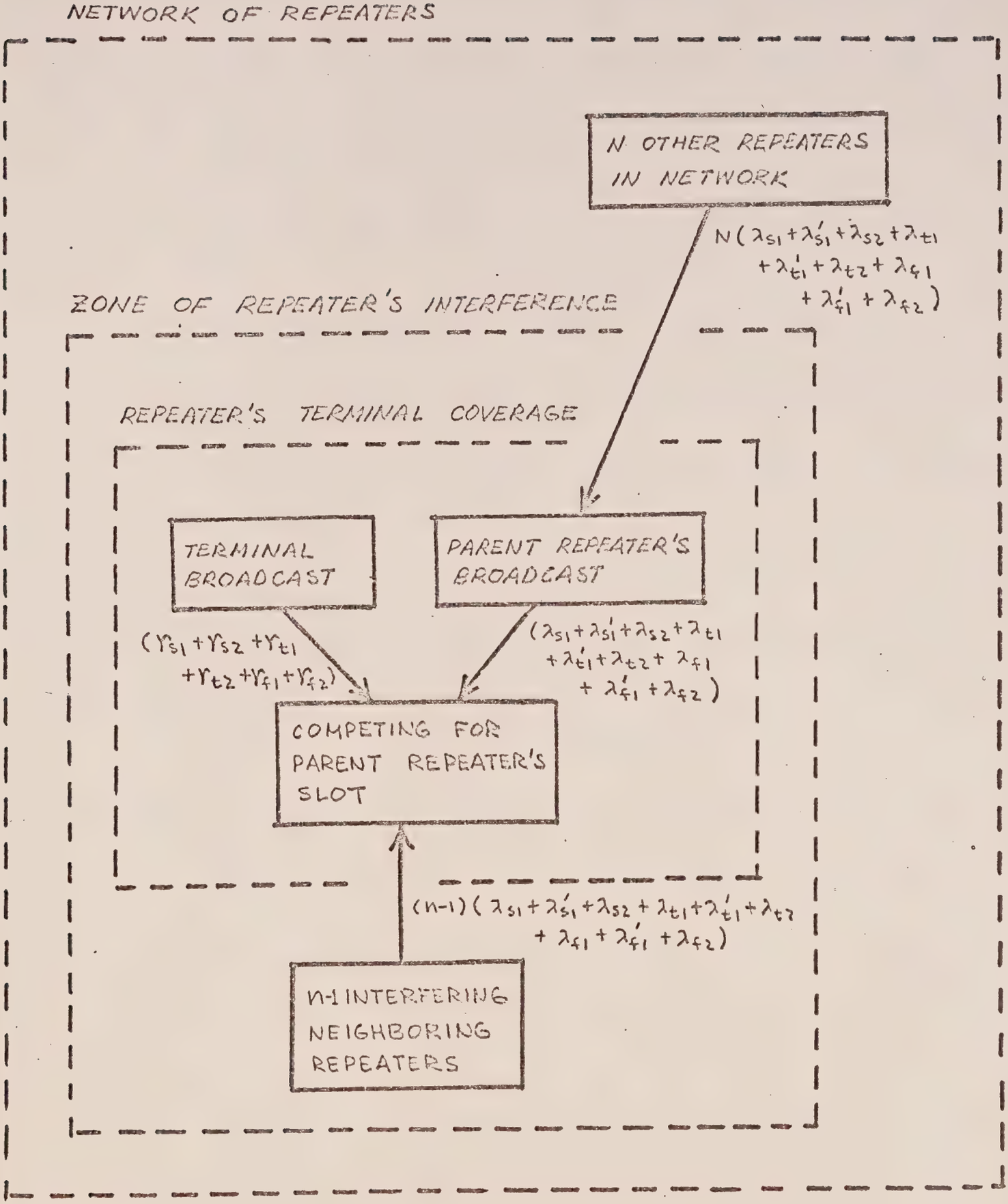

FIG. 1: THE INTERACTION OF VARIOUS PACKET RATES

- Repeaters broadcast first-time own scout packets at a rate λ_{s1}.
- Repeaters broadcast first-time other scout packets at a rate λ'_{s1}.
- Repeaters rebroadcast (own plus other) scout packets at a rate λ_{s2}.
- Repeaters broadcast first-time own tracker packets at a rate λ_{t1}.
- Repeaters braodcast first-time other tracker packets at a rate λ'_{t1}.
- Repeaters rebroadcast (own plus other) tracker packets at a rate λ_{t2}.
- Repeaters broadcast first-time own follower packets at a rate λ_{f1}.
- Repeaters broadcast first-time other follower packets at a rate λ'_{f1}.
- Repeaters rebroadcast (own plus other) follower packets at a rate λ_{f2}.
- A repeater broadcasts at a total rate $(\lambda_{s1} + \lambda'_{s1} + \lambda_{s2} + \lambda_{t1} + \lambda'_{t1} + \lambda_{t2} + \lambda_{f1} + \lambda'_{f1} + \lambda_{f2})$.
- A packet and a time slot are both of duration T.
- There are n-1 other repeaters that interfere with the broadcast of a repeater.
- There are N+1 repeaters in the broadcast network.
- A repeater is on the average an intermediate repeater on k direct routes connecting source and destination terminals.
- The ratio of the rate at which scout packets are broadcast to the rate at which follower packets are broadcast is c (i.e., $r_{s1} = cr_{f1}$).

For terminals in a single repeater area, the rate at which they successfully broadcast their basic message packets is r_{f1}. Consequently, from the viewpoint of the terminals in a single repeater area, the channel utilization is

$$\text{CHANNEL UTILIZATION} = r_{f1}T. \tag{3.1}$$

From the viewpoint of the terminals in a single repeater area, the channel traffic is composed of those packets competing for the same slot. Assuming that a terminal broadcasts and interferes over an identical area, and that a repeater broadcasts and interferes over an identical area, we see from Fig. 1 that the following packets are competing for the same slot:

(1) Packets broadcast by the terminals at a rate $(r_{s1} + r_{s2} + r_{t1} + r_{t2} + r_{f1} + r_{f2})$.

(2) Packets broadcast by the parent repeater at a rate $(\lambda_{s1} + \lambda'_{s1} + \lambda_{s2} + \lambda_{t1} + \lambda'_{t1} + \lambda_{t2} + \lambda_{f1} + \lambda'_{f1} + \lambda_{f2})$.

(3) Packets broadcast by the $(n-1)$ neighboring interfering repeaters at a rate $(n-1)(\lambda_{s1} + \lambda'_{s1} + \lambda_{s2} + \lambda_{t1} + \lambda'_{t1} + \lambda_{t2} + \lambda_{f1} + \lambda'_{f1} + \lambda_{f2})$.

Consequently, the total rate of packets competing for the same slot is

$$\begin{aligned} R = {} & (r_{s1} + r_{s2} + r_{t1} + r_{t2} + r_{f1} + r_{f2}) \\ & + n(\lambda_{s1} + \lambda'_{s1} + \lambda_{s2} + \lambda_{t1} + \lambda'_{t1} + \lambda_{t2} + \lambda_{f1} + \lambda'_{f1} + \lambda_{f2}) \end{aligned} \tag{3.2}$$

and the channel traffic is

$$\text{CHANNEL TRAFFIC} = RT. \tag{3.3}$$

If we assume exponential packet broadcast times for terminals and repeaters, and independence in their broadcast times, then the probability of a packet capturing a slot of duration T is from (3.2)*

$$P = \Pr(\text{SLOT CAPTURE}) = e^{-RT}. \tag{3.4}$$

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*In this note, the notation Pr(E) means the probability that event E occurs. Also, (3.4) is only approximately true when a repeater is attempting to capture a slot, since a repeater broadcasts packets serially, and, consequently, a repeater does not interfere with itself as does the aggregated terminal traffic.

IV Derivation of Expressions

In this section we shall derive expressions relating the channel utilization, $r_{f1}T$, to the channel traffic, RT. Essentially this will require solving for rates r_{s1}, r_{s2}, r_{t1}, r_{t2}, r_{f2}, λ_{s1}, λ'_{s1}, λ_{s2}, λ_{t1}, λ'_{t1}, λ_{t2}, λ_{f1}, λ'_{f1}, and λ_{f2} in terms of r_{f1} and R.

A. Steady-State Considerations

The rate at which terminals in a repeater's area successfully broadcast scout packets, tracker packets, and follower packets is r_{s1}, r_{t1}, and r_{f1} respectively. The rate at which a repeater successfully broadcasts own scout packets, own tracker packets, and own follower packets is λ_{s1}, λ_{t1}, and λ_{f1} respectively. However, in steady-state, the rate at which a repeater receives packets must equal the rate at which it broadcasts packets; therefore, we have

$$\lambda_{s1} = r_{s1} \quad , \tag{4.1}$$

$$\lambda_{t1} = r_{t1} \quad , \text{ and} \tag{4.2}$$

$$\lambda_{f1} = r_{f1} \quad . \tag{4.3}$$

The ratio of the rate at which scout packets are broadcast and the rate at which follower packets are broadcast is by definition c; therefore, we have using (4.1)

$$\lambda_{s1} = r_{s1} = cr_{f1} \quad . \tag{4.4}$$

We assume in steady-state the there is an equal probability of all terminals serving as the source and destination terminal (i.e., the traffic distribution is uniform). Consequently, we assume that the terminals in a repeater's area receive scout packets at a rate r_{s1}; this is the same rate at which terminals successfully broadcast scout packets. Because a terminal must send a tracker packet for each scout packet it receives, then

$$r_{t1} = r_{s1} \quad . \tag{4.5}$$

Using (4.2), (4.4) in (4.5), we have

$$\lambda_{t1} = r_{t1} = cr_{f1} \quad . \tag{4.6}$$

B. Expression for r_{s2}

The rate at which terminals rebroadcast scout packets is r_{s2}, and in steady-state this must satisfy the equation

$$r_{s2} = (r_{s1} + r_{s2}) \Pr (\text{REBROADCAST}) \quad . \tag{4.7}$$

Since the parent repeater is the only designated receiver of the packet, then, in this case, the probability of rebroadcast is the probability of not capturing the parent repeater's slot, i.e.,

$$\Pr (\text{REBROADCAST}) = 1 - P \tag{4.8}$$

where P is given by (3.4). Substituting (4.4) and (4.8) into (4.7), we can solve for r_{s2} in terms of r_{f1}, i.e.,

$$r_{s2} = c\left(\frac{1 - P}{P}\right) r_{f1} \quad . \tag{4.9}$$

C. Expression for r_{t2}

The rate at which terminals rebroadcast tracker packets is r_{t2}, and in steady-state this must satisfy the equation

$$r_{t2} = (r_{t1} + r_{t2}) \Pr (\text{REBROADCAST}) \quad . \tag{4.10}$$

Since the parent repeater is the only designated receiver of the packet, then, in this case, the probability of rebroadcast is the probability of not capturing the parent repeater's slot, i.e.,

$$\Pr (\text{REBROADCAST}) = 1 - P \quad , \tag{4.11}$$

where P is given by (3.4). Substituting (4.6) and (4.11) in (4.10), we can solve for r_{t2} in terms of r_{f1}, i.e.,

$$r_{t2} = c \left(\frac{1 - P}{P}\right) r_{f1} \quad . \tag{4.12}$$

D. Expression for r_{f2}

The rate at which terminals rebroadcast follower packets is r_{f2}, and in steady-state this must satisfy the equation

$$r_{f2} = (r_{f1} + r_{f2}) \Pr (\text{REBROADCAST}) \quad . \tag{4.13}$$

Since the parent repeater is the only designated receiver of the packet, then, in this case, the probability of rebroadcast is the probability of not capturing the parent repeater's slot, i.e.,

$$\Pr (\text{REBROADCAST}) = 1 - P \quad , \tag{4.14}$$

where P is given by (3.4). Substituting (4.14) in (4.13), we can solve for r_{f2} in terms of r_{f1}, i.e.,

$$r_{f2} = \left(\frac{1 - P}{P}\right) r_{f1} \quad . \tag{4.15}$$

E. Expression for λ'_{s1}

The rate at which repeaters broadcast first-time other scout packets is λ'_{s1}. However, a repeater will relay the own scout packet it has received from the other N repeaters if it has received it for the first time. Because scout packets flood the network, and, because, we assume hop-by-hop acknowledgement, a repeater is assured to hear at least one copy of all the own scout packets successfully broadcast by the other N repeaters. Since a repeater successfully broadcasts own scout packets at a rate λ_{s1}, then the N other repeaters are successfully broadcasting own scout packets at a total rate $N\lambda_{s1}$. Consequently, we have

$$\lambda'_{s1} = N\lambda_{s1} \quad , \tag{4.16}$$

and substituting (4.4) in (4.16), we can solve for λ'_{s1} in terms of r_{f1}, i.e.,

$$\lambda'_{s1} = cNr_{f1} \quad , \tag{4.17}$$

F. Expression for λ_{s2}

The rate at which repeaters rebroadcast (own plus other) scout packets is λ_{s2}, and in steady-state this must satisfy the equation

$$\lambda_{s2} = (\lambda_{s1} + \lambda'_{s1} + \lambda_{s2}) \Pr (\text{REBROADCAST}) \quad . \tag{4.18}$$

The probability of a repeater rebroadcasting a scout packet depends on the number of designated receivers who must receive the packet. If the scout packet is broadcast for the first time, then the probability of rebroadcast is the probability that not all of the (n-1) neighboring repeaters successfully receive the scout packet; this probability is equal to $(1 - P^{n-1})$, where P is given by (3.4). Alternatively, if the scout packet has already been rebroadcast several times and there are i repeaters remaining to receive the scout packet, then the probability of rebroadcast is equal to $(1 - P^{i})$. Consequently, we see that the probability of rebroadcast in (4.18) is a complex function of the number of previous rebroadcasts and the number of repeaters remaining to receive the scout packet. In order to make our analysis easier, we shall make the conservative assumption that

$$\Pr (\text{REBROADCAST}) = 1 - P^{n-1} \quad . \tag{4.19}$$

Substituting (4.4), (4.17), and (4.19) in (4.18), we can solve for λ_{s2} in terms of r_{f1}, i.e.,

$$\lambda_{s2} = c\ (1+N) \left(\frac{1 - P^{n-1}}{P^{n-1}} \right) r_{f1} \quad . \tag{4.20}$$

G. Expression for λ'_{tl}

The rate at which repeaters broadcast first-time other tracker packets is λ'_{tl}. We note that tracker packets are sent on a direct route from a destination terminal to a source terminal. Since a repeater broadcasts own tracker packets at a rate λ_{tl}, and assuming that a tracker packet is equally likely to be sent to the other N repeaters, then each direct route carries tracker packets at an average rate λ_{tl}/N. However, a repeater will relay the own tracker packet of another repeater, only if it is an intermediate repeater on the direct route. Consequently, we have

$$\lambda'_{tl} = k\left(\frac{\lambda_{tl}}{N}\right) , \tag{4.21}$$

where a repeater is on the average an intermediate repeater on k direct routes connecting source and destination terminals.

We can estimate k as a function of the total number of repeaters in the network (N+1), as follows. If there are (N+1) repeaters in a network, then a square-shaped network would have $(N+1)^{1/2}$ repeaters on a side. An average direct route in such a network would go through $\frac{1}{2}(N+1)^{1/2}$ intermediate repeaters. However, there are $(N+1)^2$ possible direct routes with each repeater considered as either the beginning or the end of a direct route. Hence all the direct routes in the network go through $(N+1)^2\ [\frac{1}{2}(N+1)^{1/2}]$ intermediate repeaters. Consequently, on the average, each of the (N+1) repeaters is an intermediate repeater on k direct routes where

$$k = \frac{(N+1)^2[\frac{1}{2}(N+1)^{1/2}]}{(N+1)} = \frac{(N+1)^{3/2}}{2} . \tag{4.22}$$

Finally, if we substitute (4.6) and (4.22) in (4.21), we can solve for λ'_{tl} in terms of r_{fl}, i.e.,

$$\lambda'_{t1} = c\left[\frac{(N+1)^{3/2}}{2N}\right] r_{f1} \quad . \tag{4.23}$$

H. Expression for λ_{t2}

The rate at which repeaters rebroadcast (own plus other) tracker packets is λ_{t2}, and in steady-state this must satisfy the equation

$$\lambda_{t2} = (\lambda_{t1} + \lambda'_{t1} + \lambda_{t2}) \Pr(\text{REBROADCAST}) \quad . \tag{4.24}$$

Since a repeater will rebroadcast a tracker packet until it receives an acknowledgement from the next receiver in line along the direct route, then, in this case, the probability of rebroadcast is the probability of not capturing the slot of the next receiver in line, i.e.,

$$\Pr(\text{REBROADCAST}) = 1 - P \quad , \tag{4.25}$$

where P is given by (3.4). Substituting (4.6), (4.23), and (4.25) in (4.24), we can solve for λ_{t2} in terms of r_{f1}, i.e.,

$$\lambda_{t2} = c\left[1 + \frac{(N+1)^{3/2}}{2N}\right]\left(\frac{1-P}{P}\right) r_{f1} \quad . \tag{4.26}$$

I. Expression for λ'_{f1}

The rate at which repeaters broadcast first-time other follower packets is λ'_{f1}. We note that follower packets are sent on a direct route between source terminal and destination terminal. Since a repeater broadcasts own follower packets at a rate λ_{f1}, and assuming that a follower packet is equally likely to be sent to the other N repeaters, then each direct route carries follower packets at an average rate λ_{f1}/N. However, a repeater will relay the own follower packet of another repeater, only if it is an intermediate repeater on the direct route. Consequently, we have

$$\lambda'_{f1} = k\left(\frac{\lambda_{f1}}{N}\right) \quad , \tag{4.27}$$

where a repeater is on the average an intermediate repeater on k direct routes connecting source and destination terminals. Substituting (4.3) and (4.22) in (4.27), we can solve for λ'_{f1} in terms of r_{f1}, i.e.,

$$\lambda'_{f1} = \left[\frac{(N+1)^{3/2}}{2N}\right] r_{f1} \quad . \tag{4.28}$$

J. Expression for λ_{f2}

The rate at which repeaters rebroadcast (own plus other) follower packets is λ_{f2}, and in steady-state this must satisfy the equation

$$\lambda_{f2} = (\lambda_{f1} + \lambda'_{f1} + \lambda_{f2}) \Pr (\text{REBROADCAST}) \quad . \tag{4.29}$$

Since a repeater rebroadcasts a follower packet until it receives an acknowledgement from the next receiver in line along the direct route, then, in this case, the probability of rebroadcast is the probability of not capturing the slot of the next receiver in line, i.e.,

$$\Pr (\text{REBROADCAST}) = 1 - P \quad , \tag{4.30}$$

where P is given by (3.4). Substituting (4.3), (4.28), and (4.30) in (4.29), we can solve for λ_{f2} in terms of r_{f1}, i.e.,

$$\lambda_{f2} = \left[1 + \frac{(N+1)^{3/2}}{2N}\right]\left(\frac{1 - P}{P}\right) r_{f1} \quad . \tag{4.31}$$

K. Calculating Channel Utilization

Previously we have obtained r_{s1}, r_{s2}, r_{t1}, r_{t2}, r_{f2}, λ_{s1}, λ'_{s1}, λ_{s2}, λ_{t1}, λ'_{t1}, λ_{t2}, λ_{f1}, λ'_{f1}, and λ_{f2} in terms of r_{f1} and other system parameters. We would like to obtain an expression for the channel

utilization $r_{fl}T$ as a function of the channel traffic RT. To do so we substitute (4.3), (4.4), (4.6), (4.12), (4.15), (4.17), (4.20), (4.23), (4.26), (4.28), and (4.31) into (3.2); we multiply both sides of (3.2) by T and solve for $r_{fl}T$ as a function of RT. Doing this we have

$$r_{fl}T = \frac{(P^{n-1})RT}{P^{n-2}\left\{1 + 2c + n\,(1+c)\left[1 + \frac{(N+1)^{3/2}}{2N}\right]\right\} + cn(N+1)}, \qquad (4.32)$$

where P is given by (3.4).

V Analysis of Results

We consider a 37 repeater network in a hexagonal pattern with N = 36 and n = 6.* In Figure 2, we have plotted the channel traffic, RT, versus the channel utilization, $r_{fl}T$, for several values of c (the ratio of scout to follower packets). The quantities RT and $r_{fl}T$ represent respectively the channel traffic and channel utilization of the terminals in a single repeater area. In Figure 2 we have also plotted 37 RT vs. $37r_{fl}T$, since, in some sense, these quantities represent respectively the total channel traffic and the total channel utilization of the network when considering all 37 repeater areas together.

In Figure 2, we again see the saturation behavior exhibited by Abramson in Ref. 1. Based on Ref. 3, we assume that a typical voice communication between terminals is two minutes in duration and involves 600 packets.** Thus, for c = 1/600 = .00167, the maximum channel utilization is $r_{fl}T$ = .0110 (37 $r_{fl}T$ = .407). Also, for c = .001, the maximum channel utilization is $r_{fl}T$ = .0118 (37 r_{fl} = .437); and for c = 0.0, the maximum channel utilization is $r_{fl}T$ = .0143 (37 $r_{fl}T$ = .529).

We see from the above numbers that the maximum channel utilization drops by 23% from the case c = 0.0 to the case c = 1/600. However, the case c = 0.0 represents the situation where there are no scout or tracker packets, and, thus, each terminal somehow knows the direct route to all other terminals. Consequently, in some sense, we can say that when the average terminal-to-terminal transmission involves 600 packets, then the price paid to find a direct route between the terminals is a 23% drop in channel utilization.

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*We have chosen n = 6 instead of n = 7 to account for the repeaters on the boundary.

**Ref. 3: W. Hardman, "Packet Radio Communications Requirements of a Typical Field Army," Packet Radio Temporary Note 22, February 5, 1973.

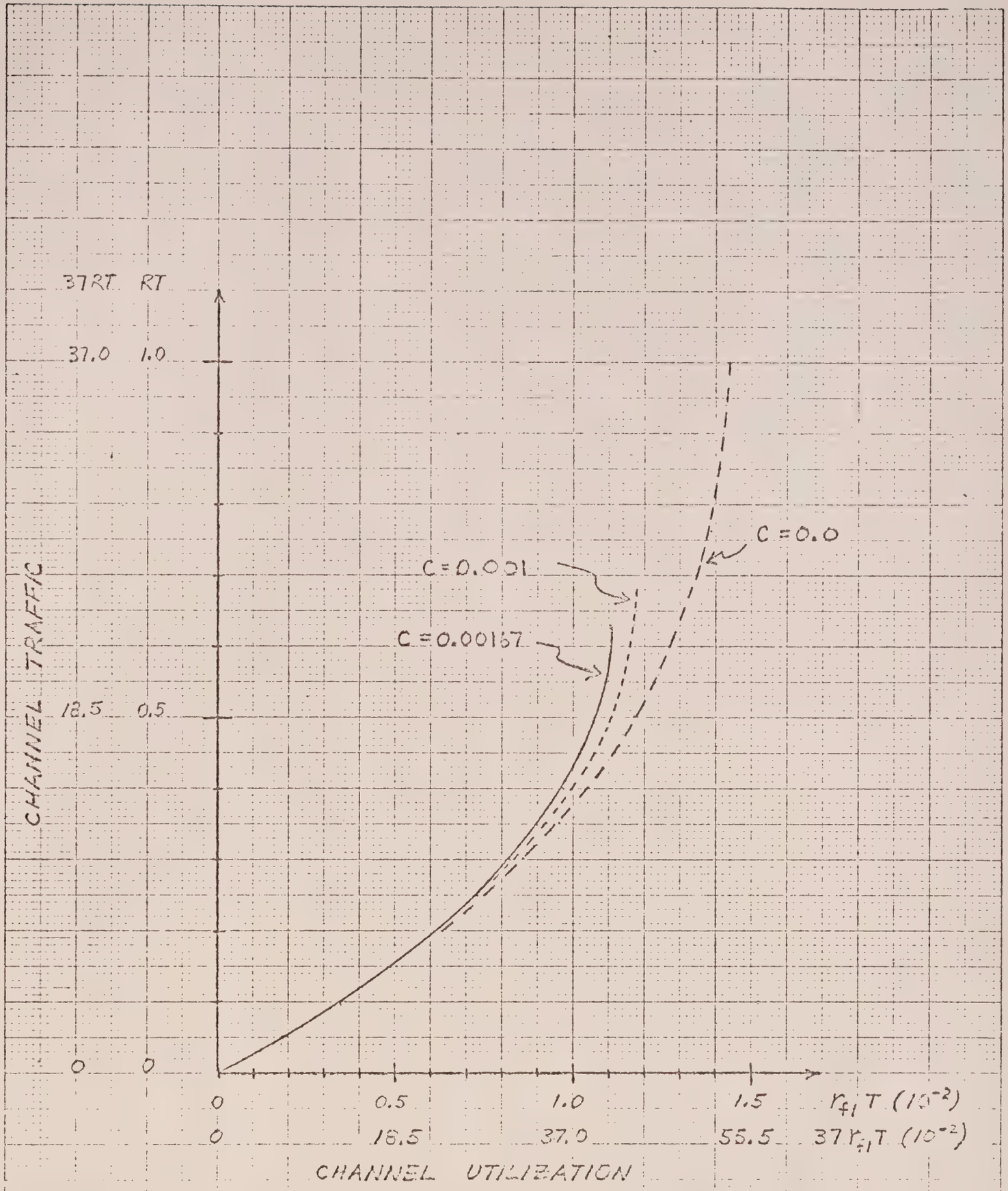

FIG. 2: CHANNEL TRAFFIC (RT) VS. CHANNEL UTILIZATION ($r_{f1}T$) *

* NOTE: C IS THE RATIO OF SCOUT PACKETS TO FOLLOWER PACKETS

It is surprising, that even in the case c = 0.0 (i.e., packets are sent along direct routes which are somehow known), that the maximum channel utilization ($r_{f1}T = .0143$) is so small. If we examine what a repeater is doing for the case c = 0.0, we find that a repeater spends approximately:

- 15% of its active time (1) receiving packets generated by its own terminals, (2) relaying into the network packets generated by its own terminals, (3) receiving packets from the network designated for its own terminals, and (4) relaying packets to its own terminals which have been generated somewhere else in the network.

- 23% of its active time (1) receiving packets destined for another repeater area, and (2) relaying packets destined for another repeater area.

- 62% of its active time receiving packets broadcast by neighboring repeaters for which it was not the intended receiving repeater (i.e., being interfered by the neighboring repeaters).

VI Concluding Remarks

Using the analysis procedures described in this note we have been able to obtain an approximate quantitative understanding of the behavior of a scout/follower broadcast system. We note from the previous section, that even when a direct route to the destination terminal is known to the source terminal, that a repeater spends over 60% of its active time receiving packets not meant for itself. Consequently, it is clear that significant improvements in broadcast efficiency can be achieved if the number of neighboring interfering repeaters can be reduced.